

The University of Chicago

A SPECTROSCOPIC STUDY
OF THE REGION OF THE DOUBLE
CLUSTER IN PERSEUS

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

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Received April 14, 1943

ABSTRACT

Spectral classes and spectroscopic absolute magnitudes have been derived from low-dispersion spectrograms for 153 early-type stars in the vicinity of the double cluster in Perseus. The material is complete to apparent magnitude 7.5 over a large region ($10^\circ \times 15^\circ$) about the double cluster and symmetrical with respect to the galactic circle; it is complete, also, to magnitude 8.5 over an area of 6° diameter symmetrical about the double cluster. A few stars have been taken which make the material complete to apparent magnitude 9.5 in a small region near the center of each cluster.

True distance moduli have been found for all stars later than O8 by using the photoelectric colors measured by Stebbins, Huffer, and Whitford. The results indicate that (1) there is a pronounced clustering of early-type supergiants in the direction of, and at the distance of, the η and χ Persei cluster, and (2) the diameter of this cluster of supergiants is considerably larger than that usually ascribed to the double cluster and may be estimated as about $5''$.

The variation in selective and total interstellar absorption across the field studied is discussed, and a reproduction shows the effect on star density caused by the considerable absorption suffered by these stars. On the bases of spectroscopic absolute magnitude, radial velocity, and interstellar line intensity, a considerable number of the stars investigated are attributed to the η and χ Persei cluster, and the most probable distance of the cluster is found to be 1920 parsecs. There is an appreciable difference between the distance as found from spectroscopic absolute magnitudes and that obtained from the galactic-rotation effect on the radial velocity of the cluster members. This discrepancy in distance, however, represents a discrepancy in distance modulus of only about 0.6 mag., which may be due to an error in the absolute magnitudes ascribed to these supergiants. The cluster may, of course, have a small peculiar velocity.

Many of the stars between apparent magnitudes 8.5 and 9.5 show the diffuse lines characteristic of rapidly rotating stars, and a number of the fainter stars show emission. It is shown that highly luminous stars of other types, such as the irregular M-type variables, appear in the same region about the double cluster. The Russell-Hertzsprung diagram for early-type stars attributed to the cluster is plotted, using the data of this investigation and that of Trumpler.

I. INTRODUCTION

It has long been known that the region of η and χ Persei, though not a particularly brilliant section of the Milky Way, contains an extraordinarily large number of early-type stars of high luminosity. In R. E. Wilson's catalogue of nonvariable c stars¹ we find, for example, 23 early-type supergiants in this region, most of them within 2° or 3° of the double cluster. Twenty of these are attributed to the η and χ Persei cluster.

In a discussion of the *Henry Draper Catalogue* stars of type B3 or earlier, Struve² emphasized a "very thick" clustering of B stars in Perseus and suggested that we are here dealing with an actual grouping in space—a suggestion which was further strengthened by the discovery that these stars possess interstellar calcium lines of comparable intensity. As such, these stars were used as a calibration point for a relation between K intensity and distance, the distance adopted being that of the cluster as determined by Trumpler.³

Shapley⁴ tabulated probable members of this group of stars and plotted a Russell-Hertzsprung diagram on the assumption that all these stars belong to the η and χ Persei system. The resulting distribution is of great interest, for it shows a large dispersion in absolute magnitude for each spectral class; it is clear that, if it is possible to plot in the

¹ *Ap. J.*, **93**, 212, 1941.

² *A.N.*, **231**, 17, 1927.

³ *Ap. J.*, **67**, 353, 1928.

⁴ *Star Clusters* ("Harvard Monographs," No. 2), 1930.

same diagram these very luminous stars and those obviously belonging to the cluster, we have an accurate means of calibrating the absolute magnitudes of early-type supergiants.

However, it is by no means certain that we may consider all the stars which Shapley plots as a physical group. For one thing, as Oosterhoff⁵ points out, the apparent diameters of the two clusters are of the order of 30', while the supergiants are spread over an area of a number of square degrees. The common radial velocity shown by many of these stars is not conclusive evidence of cluster membership, for any distant star in this direction will show a large negative velocity due to the galactic rotation effect; and the peculiar velocity of the stars might bring the galactic rotation velocity fairly close to that of the cluster stars. Of course, a radial velocity differing widely from -40 km/sec definitely excludes a star from cluster membership.

The presence of very luminous and presumably highly massive stars at the edges of galactic clusters is not a common characteristic of those known at present. Further, another sort of evidence would appear to negate the cluster hypothesis for these stars. Merrill, in his "Regional Study of Interstellar Sodium,"⁶ plots D-line equivalent widths against distances uncorrected for absorption for many of these supergiants. The stars fall at apparent distances of 1000–3000 parsecs, and the sodium intensity increases somewhat with distance. The introduction of differential interstellar absorption, however, tends to bring these stars closer together; and, since D-line intensity increases with color excess, according to Evans,⁷ these observations may not be in disagreement with the idea that these stars are in reality at the same distance.

Because of the great importance of knowing which of these supergiants can be considered as members of the η and χ Persei cluster and because proper-motion data do not appear to be capable of deciding this question as yet, a program of spectroscopic absolute-magnitude determination has been embarked on for a fairly large number of stars in the region of the double cluster. With the recent work of Morgan, Keenan, and Kellman⁸ we have for the first time a comprehensive system of absolute-magnitude and spectral-class criteria for early-type supergiants; using this system, the principal aim of this investigation is to determine, if possible, which of these stars can be considered physical members of the η and χ Persei clusters. In what follows we shall refer to the Morgan-Keenan-Kellman investigation as the "*Atlas*."

II. THE OBSERVATIONS

The stars have been classified and their luminosities determined on low-dispersion slit spectrograms; a majority of the stars were taken with the identical equipment used in establishing the criteria discussed in the *Atlas*. The brighter stars were taken at the Yerkes Observatory with a dispersion of 125 Å/mm at $H\gamma$, while the fainter stars were taken at the McDonald Observatory with the $f/2$ glass Schmidt spectrograph camera, giving a dispersion of 76 Å/mm at $H\gamma$. The plates used at Yerkes were Cramer Hi-Speed and Eastman 103a-0, while at McDonald, since film is necessary, owing to the curvature of the field, Agfa Super-Plenachrome Press film was used; the last named was ammoniated before use.

Standard stars given in the *Atlas* were used; in general, at least three luminosity classes were represented for each spectral type, and in several classes stars were taken both in luminosity class Ia and Ib to test the accuracy which can be obtained. Standard stars were taken at both observatories, so that the classification could be made by directly comparing standard stars with program stars. The spectra at Yerkes were obtained with the optimum width, as described in the *Atlas*; at McDonald it proved impossible to attain the desired width with reasonable exposure times, so that the spectra taken there are probably not of quite so good quality as those at Yerkes. Nevertheless, the width of

⁵ *Leiden Ann.*, 17, Part I, 1937.

⁶ *Ap. J.*, 86, 28, 1937.

⁷ *Ap. J.*, 93, 275, 1941.

⁸ *An Atlas of Stellar Spectra* ("Astrophysical Monographs"), 1943.

the spectra obtained there exceeds considerably that usually employed for spectral classification from slit spectra.

Since accurate color excesses are lacking for many stars included in this investigation, it was decided to obtain only one good spectrum for each star. Unless the object proved of special interest, the classifications were based solely on this. Underexposed, badly guided, or otherwise imperfect plates were not used at all, as a poor plate can contribute nothing of value to data obtained from a good one. It has, of course, been impossible to avoid using some plates which are not of sufficiently good quality for great accuracy; and in the case of broad-line stars, in particular, there is some doubt as to the classification. This has usually been indicated in the tables by a colon following the classification. The remarks which follow the tables, in so far as they refer to the appearance of the spectra, are merely indications of interesting features of these stars; it should be borne in mind that they refer to what can be seen on the dispersion used. The small dispersion used at Yerkes is of great value in minimizing rotation broadening, while the somewhat larger dispersion used at McDonald shows it much more clearly. Despite this fact, a few of the stars taken at Yerkes show considerable broadening. The plates and films used are not red-sensitive, so that no data on the behavior of $H\alpha$ was obtained.

III. THE OBSERVING PROGRAM

Although the h and χ Persei clusters are only some 40° distant from the anticenter, because of their small galactic latitude (-3°), we should expect an appreciable number of "background" supergiants in their vicinity, because early-type supergiants are known to be highly concentrated to the galactic plane. To evaluate the number of "field" supergiants in the region of the double cluster, stars were observed over a fairly large area. A region (which we shall call "Region I") was chosen running from 95° to 110° in galactic longitude and from $+5^\circ$ to -5° in galactic latitude. All stars classified in the *Henry Draper Catalogue* as type A2 or earlier and between 5.0 and 7.5 photometric magnitude were observed at Yerkes.

A second region (which we shall call "Region II") was chosen by plotting all stars of type A2 or earlier and between photographic magnitudes 5.0 and 8.5 in the Yale zone catalogues^{9, 10} on a right ascension and declination chart, made with a scale corresponding to $\delta = 60^\circ$, and then drawing a circle of radius 3° about the center of the double cluster. The area thus chosen is not strictly circular but is sufficiently symmetrical about the cluster for our purposes. All stars falling within this circle were observed, those fainter than eighth magnitude in general at the McDonald Observatory.

Region III consists of the vicinity of the clusters themselves and comprises an area about $37'$ square centered on each cluster. These two squares are the regions considered by Oosterhoff⁵ in his study of the double cluster and also include those areas studied by Trumpler^{11, 12} and Zug.¹³ All stars in Region III were observed which are brighter photographically than 9.50, according to Oosterhoff. These stars were all taken at the McDonald Observatory.

A few stars were also observed which, although they lie outside the regions chosen, are contained in Shapley's table.⁴

IV. AUXILIARY DATA USED

The only quantities directly determined in this investigation are spectral classes and absolute magnitudes. However, to derive distances from the observed data we also need accurate apparent magnitudes and very accurate color-excess data.

⁹ *Trans. Yale Obs.*, **4**, 1925; **7**, 1930.

¹⁰ The photographic magnitudes used are in *Contr. Columbia Obs.*, No. 30, 1937; No. 31, 1938.

¹¹ *Pub. Allegheny Obs.*, **6**, No. 4, 1929.

¹² *Pub. A.S.P.*, **38**, 350, 1926.

¹³ *Lick Obs. Bull.*, No. 454, 1933.

The apparent magnitudes used in this investigation have been derived from a variety of sources. It is well known that the photometric magnitudes given in the *Henry Draper Catalogue* are not uniformly accurate; the revision of the magnitudes of bright stars published recently as the "Harvard Photovisual Magnitudes of Bright Stars"¹⁴ does, however, provide magnitudes on a uniform system; and, as all the stars taken in Region I have *Mimeogram* magnitudes, these have been used. The absolute magnitudes have, however, been derived using the preliminary calibration curve given in the *Atlas*, and they are visual magnitudes. The calibration was made using the Harvard photometric magnitudes of bright stars, and so it was necessary to investigate the relation between the Harvard photometric system and that of the *Harvard Mimeogram* referred to above. A plot of the two magnitude systems for those stars in Region I used in this work shows that, while there is little systematic difference for the dwarf stars, the supergiants appear to be systematically fainter by about 0.1 mag. in the photometric system than in the photovisual system. This conclusion was checked by comparing the magnitudes of early-type supergiants of the *Atlas*, where a systematic difference in the same sense of 0.07 mag. was found. Thus, a correction of -0.1 mag. was applied to the absolute magnitudes of the supergiants of Region I, whereas no change was made in the case of stars of lower luminosity.

Since many stars observed in Region II do not have Harvard Photovisual System magnitudes, those used are the regular Harvard photometric (two-decimal) magnitudes, if available; if not, the magnitudes given in the catalogue of Stebbins, Huffer, and Whitford¹⁵ are used. These magnitudes were obtained by photoelectric measures, using the Harvard photometric magnitudes as standards. The visual magnitudes of the remaining stars were taken from the *Henry Draper Catalogue* and are simply the reduced *Bonner Durchmusterung* magnitudes. The probable error of these magnitudes has been found by Stebbins, Huffer, and Whitford to be about 0.3 mag.

The magnitudes of the stars in Region III, with one exception, have been taken from the work of H. Vogt,¹⁶ whose scale and zero point were set by reference to the Potsdam magnitudes of the Pleiades and some stars belonging to the double cluster. Since it appears that there is a difference in zero point, Potsdam *minus* Harvard, of 0.28 mag.,¹⁷ Vogt's magnitudes have been correspondingly reduced. One of the stars in Region III is given the magnitude listed in the *Henry Draper Catalogue*. Magnitudes for the stars not included in these three regions have been taken from the Harvard Photovisual System or the *Henry Draper Catalogue*, the correction for supergiants again having been made.

A number of the stars studied in this investigation are double, either spectroscopically or visually, and the magnitude of the brighter component has been computed from the difference in magnitude, usually taken from Aitken's *Catalogue of Double Stars*, and the distance modulus corresponding to this component has been found. In all such cases the apparent magnitude of the brighter component is tabulated.

The other auxiliary datum required for obtaining the distance of a star is the total visual absorption. It has proved invaluable to use the photoelectric colors of Stebbins, Huffer, and Whitford¹⁵ for the determination of color excess; and in agreement with them we determine the total visual absorption by multiplying the color excess by 7.¹⁸ Photoelectric colors are available for many of the supergiants in this region, as well as for some other B stars. The determination of color excess, however, demands information on the normal colors as well as measured colors themselves. The normal colors tabulated in "The Colors of 1332 B Stars" were determined by considering those stars near enough

¹⁴ Payne-Gaposchkin, *Harvard Mimeograms*, Ser. III, No. 1, 1938.

¹⁵ *Ap. J.*, 91, 20, 1940.

¹⁶ *Pub. Heidelberg*, 8, No. 3, 1932.

¹⁷ *Harvard Ann.*, 89, 65, 1932.

¹⁸ *Ap. J.*, 90, 209, 1939.

to be presumably unreddened.¹⁹ Obviously, a large percentage of these are dwarf stars, and there is no a priori reason why the supergiants should possess the same normal colors as these dwarf B and A stars.

The *Atlas* tabulates a number of very luminous early-type stars, for most of which photoelectric colors are available. Assuming the normal colors tabulated by Stebbins, Huffer, and Whitford, the color excesses were computed; and, although most of these stars have fairly large color excesses, we find, for a few of the stars, data as given in Table 1. Of these stars, perhaps ρ Leonis is the most interesting, as it has a galactic lati-

TABLE 1

Type	Star	Color Excess	Type	Star	Color Excess
B1.....	ρ Leo	0.01	A0.....	η Leo	-0.05
B8.....	β Ori	.00	A2.....	α Cyg	-0.05
A0.....	13 Mon	-0.03			

tude of $+54^\circ$, and thus its true distance above the plane of the Galaxy must be such that it is practically out of the absorbing layer, which presumably lies within 250 parsecs of the galactic plane.²⁰ It must then suffer at least 0.03 mag. color excess on the photoelectric scale, so that, even allowing for a possible error in the measure or extreme transparency in that direction, as is indicated somewhat by Hubble's nebular counts,²¹ there seems to be evidence that the normal color of a B1 supergiant is really a little bluer than that adopted heretofore, when measured photoelectrically.

For the A-type supergiants tabulated above, there seems no doubt but that this is the case, α Cygni supplying the best evidence of all. For this star must have suffered at least some color excess—probably 0.03 mag. or so, assuming a mean coefficient of absorption—so that even a fairly large error would not account for the discrepancy.

The stars α Cygni and ρ Leonis may be exceptional, but the supergiants in the region of the Perseus cluster are equally so. On the basis of this evidence the author has adopted as normal colors for supergiants values differing from those tabulated in the list of "1332 B stars" by 0.00 at B0 and -0.05 at A2, with appropriate intermediate corrections. The effect observed, if real, probably is caused by the difference in strength of the hydrogen lines in supergiant and dwarf, thus increasing toward A0.

It should be remarked that the maximum effect of this correction, at A2, will be a change of 0.35 in the distance modulus, in the sense that the distance of the star is decreased. The change, however, becomes comparable with the probable error of the measures only around B5, the earlier stars being little affected.

The photoelectric colors are used wherever available, and for stars which appear to be at roughly the distance of the cluster the color excesses have been estimated from a consideration of the change of color excess across the field, which will be discussed later in the paper. For stars appearing to be definitely closer than the cluster, i.e., dwarfs, the true distance moduli were computed, assuming a mean coefficient of absorption of 0.12 mag. per kiloparsec on the photoelectric scale. The true distances were found from a graph giving the relation between true and apparent distance for a total (visual) absorption of 0.8 mag. per kiloparsec; and, when the true distances were found, the appropriate color excess was computed, assuming uniformity of the absorbing layer.

¹⁹ *Pub. Washburn Obs.*, 15, Part V, 1934.

²⁰ Stebbins, Huffer, and Whitford, "Selective Absorption in Space near the Sun," *Ap. J.*, 94, 215, 1941.

²¹ *Ap. J.*, 79, 41, 1934.

V. COMPARISON WITH OTHER OBSERVERS

We may compare the present spectral types with those of other observers for supergiants and less luminous stars separately. The 23 objects observed in common with the c star list of Wilson¹ show a mean difference of 0.7 subclass, with a negligible systematic difference. Some of the mean difference is caused by the rather liberal use of class A1 in the present work.

Neglecting 8 stars which show a difference of more than 5 subclasses, 96 nonsupergiants observed in common with the *Henry Draper Catalogue* show a mean difference of 1.5 subclasses and a systematic difference of $\frac{1}{2}$ subclass, in the sense that the types of the present work are in general earlier than those of the Harvard observers.

Thirteen objects have been observed in common with Trumpler.^{12, 13} These show a mean difference of 0.9 subclass and a systematic difference of 0.7 in the sense that my types are earlier than Trumpler's. Comparison with 6 dwarf emission stars in Merrill's lists²² shows a mean difference of 1.2 subclass and shows that my classes are systemati-

TABLE 2
STARS WHOSE PRESENT CLASSIFICATION DIFFERS CONSIDERABLY
FROM THE *Henry Draper Catalogue*

Star	Class	HD Class	Remark
HD 9105.....	B5	B0p	The spectrum has changed. See note in tables
12150.....	B1	B8	
13661.....	B2e	B8	
14299.....	B2	B9	
14331.....	B0	B9	
14434.....	O7	B2	
14520.....	B1	B9	
15990.....	B3:	B9	
19820.....	O9	B5	

cally 1 subclass earlier than Merrill's. It should be said that these stars are quite difficult to classify accurately.

Twenty-two stars in the Victoria catalogue of radial velocities²³ give a mean difference of 0.7 subclass and a negligible systematic difference. From these comparisons we may conclude that the classes of supergiants are in good agreement with other modern determinations, that the dwarfs are classified earlier by about 0.1 spectral class than in other classifications, and that the types should be accurate to about 0.1 of a spectral class in general but that the accidental error may reach 0.2 of a spectral class occasionally. This is especially true of stars with rotational broadening and of dwarfs in the range B8-A2.

The classification of a few stars shows a considerable deviation from the *Henry Draper Catalogue*; these are given in Table 2. These stars are all fainter than magnitude 7.5 except HD 9105 and HD 19820. It is apparent that there are many more early B stars than the *Henry Draper Catalogue* would indicate.

The accuracy of the absolute magnitudes derived in this investigation is rather hard to evaluate. With the large range in absolute magnitude among the early-type stars established in recent years, the accuracy obtainable from spectroscopic criteria has somewhat decreased. Thus, although the criteria of luminosity are plainly marked for all the classes considered here except for the stars earlier than O9, the error in absolute magni-

²² *Ap. J.*, 78, 87, 1933; 96, 15, 1942.

²³ *Pub. Dom. Ap. Obs.*, 5, 99, 1931.

tude caused by a rather small error in luminosity classification can be quite serious. In the most serious case here considered, namely A2, there is a difference of 2 mag. between luminosity classes Ia and Ib. Even with the present somewhat scanty material, this difference of luminosity class will almost certainly be noted; but accurate classification of a star within this 2-mag. range is quite difficult with the type of plates used in the present work. An uncertainty of a magnitude is to be fully expected in the absolute magnitudes of this investigation, in the case of the most luminous stars. For dwarfs with good lines the accuracy may be somewhat better.

VI. OBSERVATIONAL RESULTS

The observational results of this investigation are given in Tables 3, 4, 5, and 6. The content of each table is as follows:

Table 3 contains those stars observed in Region I. Columns give HD number; galactic co-ordinates, which were computed for all the stars; the photovisual magnitude, as described above; the revised spectral class and absolute visual magnitude; the color excess, as computed from the colors of Stebbins, Huffer, and Whitford or (in parentheses) estimated from position in the field or computed as described above. Column 8 gives the true distance modulus, $m_0 - M$, where m_0 is the magnitude the star would have had were it not obscured. Then follows the radial velocity for those stars for which it is known; an asterisk in the remarks column indicates a remark following the table.

Figure 1, *a* and *b*, shows the stars in Table 3. Those stars which appear to be nearer than 500 parsecs are plotted in Figure 1, *a*; those which appear to be farther than 500 parsecs are plotted in Figure 1, *b*. In the latter diagram the stars which are considered to be members of the η and χ Persei cluster are represented by filled circles.

Table 4 contains all the stars observed in Region II, with the exception of those in Table 3. The columns are the same except that equatorial co-ordinates for 1900 are given. The two-decimal magnitudes are the Harvard photometric magnitudes; the one-decimal magnitudes are from Stebbins, Huffer, and Whitford; and the one-decimal magnitudes followed by a colon are the reduced BD magnitudes.

In Figure 2 we have plotted all the stars observed in Region II which have photographic magnitudes between 5.0 and 8.5, i.e., all those in Table 4 and those in Table 3 which fall within the circle defining Region II. Those stars which are believed to be members of the double cluster are represented by filled circles. The large circles indicate the size of the two clusters as found by Trumpler for stars of the seventeenth magnitude. We may note that the material is complete for early-type stars to apparent photographic magnitude 8.5.

Table 5 contains those stars observed in Region III. Columns give: the designation; the number of the star in Oosterhoff's catalogue;⁵ the visual magnitude, as described above; the spectral type and visual absolute magnitude; the color excess, as in the other tables; the true distance modulus; and the asterisks indicating remarks. It is considered probable that all these stars are physical members of the η and χ Persei cluster.

Table 6 gives data on several stars observed but not belonging in any of the other tables.

In all the tables a dagger before the designation indicates that the star is thought to be a member of the η and χ Persei cluster; a question mark indicates that the star may be a member. In the notes "ADS" refers to Aitken's *Double Star Catalogue* and "MWC" and "Mt. W." to the Mount Wilson Be star lists.²²

General conclusions.—Some conclusions which may be drawn from the tables and figures appear to be the following:

1. Among early-type stars brighter than magnitude 7.5, i.e., those in Table 3 and Figure 1, *a* and *b*, the distribution of the stars nearer than 500 parsecs is fairly uniform, while that of the stars farther than 500 parsecs shows a marked concentration about the

TABLE 3

HD	l	b	m_{pv}	Sp.	M_v	C.E.	$m_0 - M$	V	Re- marks
8965.....	95.4	-1.8	7.21	B0	-3.2	0.18	9.2	+ 0.6	
9105.....	95.1	+1.3	7.39	B5	-6.6	.36	11.5	-39.9	*
9311.....	95.8	-1.3	7.17	B5	-5.7	.27	11.0	-38.1	*
9812.....	96.7	-3.2	7.45	B3	-2.2	(.08)	(9.1)	.....	*
9878.....	96.0	+0.4	6.60	B8	0.0	(.02)	(6.5)	.....	
10107.....	97.0	-2.7	6.89	B9	-1.8	(.05)	(8.4)	.....	
10260.....	96.8	-0.7	6.64	B8	-1.0	.00	7.6	.....	
10293.....	97.3	-3.1	6.31	B8	-1.0	(.03)	(7.1)	.....	*
10362.....	96.8	-0.4	6.43	B8	-2.1	(.05)	(8.2)	.....	
10425.....	97.0	-1.2	5.79	B8	-0.5	(.02)	(6.2)	var.	*
10543.....	97.8	-4.1	6.32	A2	+0.3	(.02)	(5.9)	+ 5.1	*
10587.....	98.0	-4.5	6.11	A1	+1.0	(.01)	(5.0)	+ 5.3	
11606.....	98.8	-2.0	7.02	B1 _{ne}	-1.9	.11	8.2	+12.5	*
11669.....	98.4	-0.1	8.04	A0	+0.6	(.03)	(7.2)	.....	*
11857.....	98.5	+0.4	6.04	B7	-0.8	(.03)	(6.6)	.....	
11860.....	99.0	-1.6	6.54	A1	+1.0	(.01)	(5.5)	.....	
11946.....	97.8	+3.2	5.20	A0	+0.6	(.01)	(4.5)	+ 5.0	*
12112.....	99.3	-1.2	6.62	A3	0.0	(.02)	(6.5)	.....	
12279.....	98.0	+3.6	5.99	A0	+0.6	(.01)	(5.3)	-29.1	*
12301.....	98.2	+3.1	5.64	B8	-5.9	.22	10.0	-20.4	*
12365.....	99.3	-0.4	7.43	B9	-0.3	(.04)	(7.4)	.....	
12468.....	98.2	+3.8	6.49	B9	+0.2	(.02)	(6.2)	- 4.2	*
†12953.....	100.7	-2.4	5.67	A1	-6.6	.18	11.0	-37.2	
†13267.....	101.3	-3.0	6.36	B8	-6.1	.16	11.3	-34.4	
13427.....	99.2	+3.9	7.36	A1	+1.0	(.02)	(6.2)	.....	
†13476.....	101.2	-2.0	6.39	A2	-6.1	.26	10.7	-38	
†13841.....	102.2	-3.3	7.22	B0.5	-4.9	.15	11.1	-39.4	
†13854.....	102.2	-3.3	6.46	B1	-6.6	.18	11.8	-40.0	*
14010.....	99.8	+3.7	7.05	B9	-6.6	.26	11.8	-47.0	*
†14134.....	102.4	-3.1	6.63	B3	-6.1	.24	11.0	-43.4	*
†14143.....	102.4	-3.1	6.64	B2	-6.1	.27	10.8	-45.2	*
14171.....	100.0	+3.7	6.44	A0	+0.1	(.02)	(6.2)	-25.8	
14172.....	101.5	-0.4	6.83	A2	+1.4	(.01)	(5.4)	.....	
†14322.....	103.1	-4.2	6.81	B8	-5.9	.17	11.5	-37	
†14433.....	102.7	-2.9	6.42	A1	-6.1	.25	10.8	-46.1	
14489.....	103.3	-4.2	5.17	A1	-6.6	.16	10.6	-16	*
†14535.....	102.9	-2.8	7.35	A2	-5.6	.31	10.8	-53	
†14542.....	102.8	-2.7	6.85	B9	-6.1	.33	10.6	-51.4	
14817.....	101.6	+1.3	7.58	B8	0.0	(.04)	(7.3)	.....	*
†14818.....	103.4	-3.3	6.26	B2	-6.1	.27	10.5	-47.0	*
†14899.....	103.3	-2.6	7.38	A0	-5.1	(.32)	(10.2)	-42.0	
†14956.....	103.2	-2.2	7.16	B2	-6.1	.37	10.7	-30.3	
15102.....	101.3	+2.9	7.44	A0	+0.6	(.03)	(6.6)	.....	
15253.....	104.3	-4.1	6.86	A1	-1.1	(.04)	(7.7)	.....	*
†15316.....	103.5	-1.9	7.12	A2	-5.6	.40	9.9	-44	*
†15497.....	103.8	-2.0	7.01	B5	-6.1	.46	9.9	-35.4	*
15640.....	103.0	+0.2	7.43	A1	+1.0	(.02)	(6.3)	.....	*
15641.....	103.6	-1.2	8.14	A3	+1.7	(.02)	(6.3)	.....	*
16218.....	102.6	+2.9	6.71	A0	+0.1	(.02)	(6.5)	.....	
16230.....	102.6	+2.9	7.45	A2	+1.4	(0.02)	(5.9)	.....	

TABLE 3—Continued

HD	<i>l</i>	<i>b</i>	<i>m_{pV}</i>	Sp.	<i>M_v</i>	C.E.	<i>m₀ - M</i>	<i>V</i>	Re- marks
16349.....	102°7	+3°0	7.23	A2	-0.2	(0.03)	(7.2)	.....	*
16524.....	105.5	-2.7	7.39	B6	-0.4	(.04)	(7.5)	.....	
16616.....	103.1	+2.9	7.22	A2	+0.3	(.03)	(6.7)	.....	
16718.....	104.7	-0.3	7.42	A0	-0.4	(.04)	(7.5)	.....	*
16727.....	106.3	-3.6	5.72	B8	0.0	(.02)	(5.6)	.....	
17198.....	107.4	-4.4	7.42	A0	+0.6	(.03)	(6.6)	.....	*
17217.....	106.7	-2.9	6.92	A2	+0.8	(.02)	(6.0)	.....	
17505.....	104.9	+1.6	7.15	O7	.....	.24	.....	-17	*
17581.....	105.9	-0.3	6.29	A3	+1.7	(.01)	(4.5)	-4.8	*
17743.....	108.6	-4.9	6.91	B8	0.0	(.03)	(6.7)	.....	*
18352.....	105.4	+2.8	6.86	B2	-1.5	.12	7.5	-1.5	
18439.....	108.4	-2.4	7.02	A2	+0.8	(.02)	(6.1)	.....	
18473.....	106.3	+1.5	7.27	A1	0.0	(.03)	(7.1)	-1.6	*
18537.....	109.9	-4.8	5.42	B8	-0.5	.00	5.9	-4.1	*
18538.....			6.94						
18876.....	105.0	+4.7	7.37	B7	-1.4	(.06)	(8.4)	-2.9	
19243.....	105.7	+4.3	6.49	B2 _{ne}	-1.5	.26	6.2	-24.7	*
19536.....	106.9	+3.0	7.14	A0	+0.1	(.03)	(6.8)	+12.8	*
19820.....	107.8	+2.3	7.43	O9	-4.2	.32	9.4	-4.2	*
20041.....	109.3	+0.4	5.82	A0	-6.6	.33	10.1	-13	*
20536.....	107.2	+4.8	6.63	B9	-0.8	(.03)	(7.2)	-8.3	
21203.....	108.9	+3.8	6.69	B9	+0.2	(.02)	(6.4)	+3.8	*
21427.....	109.6	+3.3	6.36	A1	0.0	(0.02)	(6.2)	+13.1	*

NOTES TO TABLE 3

HD No.

9105. MWC 13. This interesting star, which had bright $H\beta$, $H\gamma$, and $H\delta$ at the time of the Harvard observations and which also showed several other lines in emission, appears to be a very luminous supergiant. Bright $H\alpha$ has been noted for many supergiants, but it is definitely peculiar for a supergiant to show as many bright lines as this star did at one time. See *Pub. A.S.P.*, **34**, 180, 1922, for a discussion of this star by Merrill and Humason. The star now has a sharp-line spectrum with strong interstellar H and K lines.
9311. ADS 1209.
9812. ADS 1262.
10293. ADS 1334.
10425. ADS 1344. Radial velocity varies from -4 to -51 km/sec. See *Dom. Ap. Obs.*, **1**, 287, 1921.
10543. ADS 1359.
11606. MWC 21. The lines are very broad and $H\beta$ is weakly bright.
11669. ADS 1531. The lines show considerable broadening.
11946. ADS 1571.
12279. Spectroscopic binary?
12301. A note in Miss Payne's c star catalogue indicates emission lines in this star, but nothing extraordinary is seen on my spectra.
12468. Spectroscopic binary?
13854. MWC 31. Emission at $H\alpha$ according to Merrill.
14010. ADS 1759.
14134. MWC 32. Emission at $H\alpha$ according to Merrill.
14143. ADS 1766. This star probably has emission at $H\alpha$ according to Merrill.
14489. ADS 1802. This star is 9 Persei, an A1 supergiant which agrees in luminosity and position with the cluster stars but which is not a member, if the radial velocity is constant.
14817. ADS 1833.
14818. MWC 45. Emission at $H\alpha$ according to Merrill.
15253. ADS 1878.

NOTES TO TABLE 3—*Continued*

- 15316, 15497. These stars, although not having distance moduli quite as large as the other cluster stars, are considered to be cluster members because of their large color excess, which introduces uncertainty in the distance, and because their radial velocities and positions agree well with the other members of the double cluster. Nevertheless, they are neither included in the computation of the distance of the cluster nor plotted in the Russell-Hertzsprung diagram of cluster members.
15640. ADS 1932.
15641. ADS 1933.
16349. The $S\text{I}$ II lines are abnormally strong, the star in this respect resembling θ Aurigae. However, this object differs from θ Aurigae in showing more faint lines, evidently corresponding to a later type and, in addition, possessing a normal K line for its type. This star is undoubtedly somewhat above the main sequence.
16718. ADS 2058.
17198. ADS 2115.
17505. ADS 2161. The velocity is variable; see Plaskett, *Dom. Ap. Obs.*, 5, 18, 1931.
17581. The metallic lines seem a little too strong for the K line in this star. This object may be peculiar as the HD type is A0 with the remark that "a line at about λ 4174 is very strong." This line does not appear extraordinarily strong on my spectra. Harper, in *Dom. Ap. Obs.*, 4, 39, 1927, gives the velocity-curve of this object, which is a spectroscopic binary, and a table of line intensities.
17743. ADS 2185.
18473. The $S\text{I}$ II lines are abnormally strong, and the spectrum generally resembles θ Aurigae. Unlike HD 16349, the K line here is weak or absent. This star was announced as a spectroscopic binary with a range of 63 km/sec in *Pub. David Dunlap Obs.*, 1, No. 3, 1939, and the presence of strong $S\text{I}$ II lines noted. According to the above, the star is a spectrum variable also.
- 18537-8. ADS 2270. The stars were not observed separately.
19243. MWC 61. $H\beta$ appears as a very weak absorption, while the other hydrogen lines are very broad. The helium spectrum, however, appears fairly sharp.
19536. Probably a spectroscopic binary, according to *Pub. David Dunlap Obs.*, 1, No. 3, 1939.
19820. This star is an O-type double-line binary. The orbit has been computed by Pearce, in *Dom. Ap. Obs.* 4, 67, 1927. It is also an Algol type eclipsing variable of small range, CC Cassiopeiae.
20041. ADS 2424.
21203. ADS 2538.
21427. ADS 2563.

double cluster in Perseus ($l = 102.5^\circ$, $b = -3^\circ$). Since the material is complete to apparent photometric magnitude 7.5, there can be no doubt that there is a real clustering of supergiants in the direction of the h and χ Persei cluster.

2. By reference to the spectroscopic distance moduli and radial velocities of these stars, one sees that there is good evidence that most of these stars in the *direction* of the cluster actually are members of a physical group at approximately the same *distance*. Thus we are entitled to speak of a "cluster of supergiants" in the direction of the double cluster in Perseus.

3. Among early-type stars between magnitude 7.5 and 8.5, i.e., those in Table 4, there are a number of stars whose positions with respect to the double cluster and whose distance moduli indicate an extension of the cluster of supergiants to fainter magnitudes. Also, there are a number of stars in Table 4 whose membership in the cluster is not certain but distinctly possible.

4. For fainter stars which are almost certainly true members of the double cluster, i.e., those in Table 5, we find distance moduli which agree within the limits of error with those found for the stars belonging to the cluster of supergiants. We will further see that the distance of all these stars in the three regions agrees well with the distance of the h and χ Persei cluster, as judged from the main sequence observed by Trumpler.

5. The diameter of the cluster of early-type stars presumably associated with the double cluster exceeds considerably that heretofore adopted for the double cluster. The diameter of the "extended cluster" surrounding h and χ Persei may be estimated as close to 5° , in comparison with that of the cluster as defined by fainter stars, which is judged to be about $1\frac{1}{2}^\circ$. There seems to be little doubt that the double cluster in Perseus is surrounded by a group of very luminous early-type stars whose presence can hardly be coincidental.

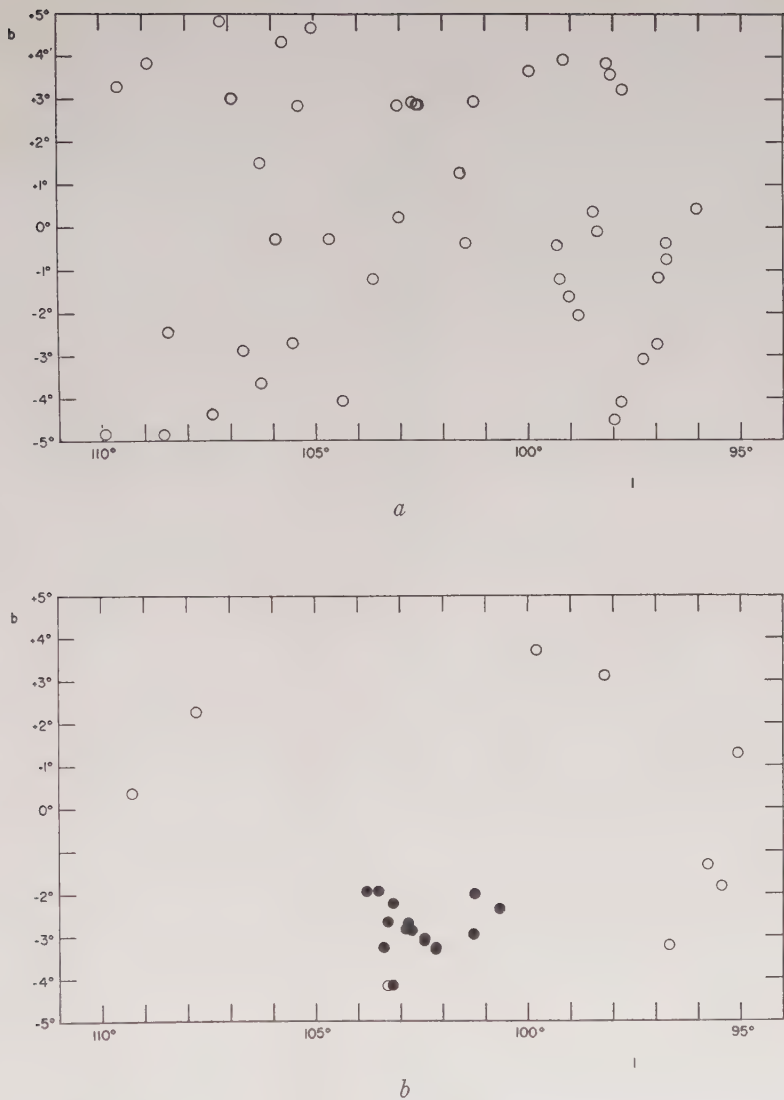


FIG. 1.—Stars with spectra as early as A2 in the *Henry Draper Catalogue* and with photometric magnitudes between 5.0 and 7.5 in the region shown. Fig. 1, *a*, shows those stars which have spectroscopic absolute magnitudes which put them within 500 parsecs, while Fig. 1, *b*, shows those stars with distances greater than 500 parsecs. In the second plot those stars considered to be members of the η and χ Persei cluster are represented by filled circles. The galactic co-ordinates of the double cluster are: $l = 102.5^\circ$, $b = -3^\circ$. The only open circle near the double cluster represents the star 9 Persei.

TABLE 4

HD	R.A.	Dec.	m_v	Sp.	M_v	C.E.	$m_0 - M$	V	Re- marks
11866.....	1 ^h 51 ^m 5	57°22'	8.1:	A2	+1.4	(0.02)	(6.6)	.....	
?12150.....	1 54.2	57 43	8.4:	B1	-3.8	(.19)	(10.9)	.....	
12709.....	1 59.4	56 50	8.0:	B3	-2.2	(.10)	(9.5)	.....	
†12856.....	2 0.9	56 38	8.6	B0.5 _{ne}	-3.5	.16	11.0	.....	*
12928.....	2 1.5	58 23	8.6:	B8	0.0	(.05)	(8.2)	.....	
12994.....	2 2.1	56 34	8.2:	B8 _n	-0.5	(.06)	(8.3)	.....	*
†13051.....	2 2.6	56 31	8.7	B0.5	-3.9	.15	11.6	.....	*
13088.....	2 3.0	58 41	8.0:	A1	+1.0	(.03)	(6.8)	.....	
13268.....	2 4.6	55 41	8.1	O7 _n	.....	.11	.....	.....	*
†13402.....	2 5.9	59 4	8.2:	B0	-4.8	(.25)	(11.2)	.....	
13412.....	2 6.0	58 20	8.2:	Ap	.....	.....	.....	.....	*
†13621.....	2 7.8	54 51	8.06	B0.5	-4.8	(.18)	(11.6)	.....	*
13633.....	2 7.9	58 1	7.96	B8	-1.0	(.06)	(8.5)	.....	*
13661.....	2 8.1	54 4	8.6:	B2 _{ne}	-2.5	(.13)	(10.2)	.....	*
13669.....	2 8.2	55 20	8.51	B5 _n :	-2.4	(.12)	(10.1)	.....	*
13716.....	2 8.6	57 18	8.4	B0.5	-4.8	.16	12.1	-60.1	
13717.....	2 8.6	55 8	8.01	B9	-0.8	(.06)	(8.4)	var.	*
†13744.....	2 8.9	57 50	7.8	A1	-5.3	.32	10.9	-51	
†13745.....	2 8.9	55 32	7.96	O9.5	-4.8	.14	11.8	-32	
?13831.....	2 9.7	56 17	7.9	O9.5:	-2.6	.09	9.9	-31	
†13866.....	2 10.0	56 15	7.4	B2	-4.2	.14	10.6	-48.8	
?13890.....	2 10.2	56 19	8.9:	B1 _{ne}	-4.8	(.14)	(12.7)	.....	*
13910.....	2 10.4	56 54	8.2:	A0 _n	+0.6	(.04)	(7.3)	- 1	*
13970.....	2 10.8	56 11	8.6	B1 _n	-1.9	.14	9.5	-27	*
†14052.....	2 11.4	56 45	7.98	B1	-4.8	(.24)	(11.1)	-41	
?14053.....	2 11.4	56 33	8.3	B3	-5.6	.14	12.9	-49	
14183.....	2 12.6	59 4	8.0:	A2	+1.4	(.02)	(6.5)	.....	
14210.....	2 12.8	56 52	8.12	B9	-0.8	(.06)	(8.5)	-39	
14299.....	2 13.6	59 9	8.6:	B2	-2.5	(.15)	(10.0)	.....	
?14331.....	2 13.9	55 22	8.81	B0	-4.8	(.17)	(12.4)	.....	
†14357.....	2 14.1	56 25	8.24	B2	-4.2	(.22)	(10.9)	-40	
†14434.....	2 14.8	56 27	8.4	O7 _n	.....	.14	.....	.....	*
†14443.....	2 14.9	56 42	7.81	B2	-4.8	(.24)	(10.9)	-39	
14581.....	2 16.3	56 24	8.35	B9	-1.8	(.10)	(9.4)	.....	
14646.....	2 16.8	57 24	8.8:	A0	+0.6	(.04)	(7.9)	-12	
14722.....	2 17.4	53 46	8.2:	B2	-1.5	(.08)	(9.1)	.....	
14795.....	2 18.0	59 33	7.52	B6	-0.4	(.04)	(7.6)	.....	*
14825.....	2 18.3	57 44	7.88	A3	+1.7	(.02)	(6.0)	+ 2	*
14827.....	2 18.3	54 48	7.51	A0	-1.4	(.06)	(8.5)	.....	*
14864.....	2 18.8	57 3	8.6:	A0	-0.4	(.06)	(8.6)	.....	
14871.....	2 18.9	55 38	8.0:	B5	-0.6	(.05)	(8.2)	.....	
14947.....	2 19.5	58 25	8.04	O5 _e	.....	.....	.....	-53.7	*
15090.....	2 20.8	56 8	8.5:	A1	+1.0	(.03)	(7.3)	.....	
15124.....	2 21.1	56 49	8.2:	B3:	-1.1	(.07)	(8.8)	.....	
15332.....	2 23.0	56 13	8.1:	A1	+1.0	(.03)	(6.9)	.....	*
15485.....	2 24.5	54 50	8.5:	A3	+1.7	(.03)	(6.6)	.....	
†15642.....	2 25.8	54 54	8.6	O9.5 _n	-3.4	.05	11.6	.....	*
†236970.....	2 26.2	55 52	9.3:	Comp.	-5.1	(.50)	(10.9)	.....	*
†15690.....	2 26.3	57 5	8.2:	B2	-5.6	.39	11.1	.....	
15963.....	2 28.9	57 38	7.98	Bp	.....	.....	.....	.....	*

TABLE 4—*Continued*

HD	R.A.	Dec.	m_V	Sp.	M_V	C.E.	$m_0 - M$	V	Re- marks
15990.....	2 h 29 m 1	55° 30'	8.2:	B3:	-1.1	(.07)	(8.8)		*
16012.....	2 29.3	57 17	8.2:	B9	+0.2	(.04)	(7.7)	.....	
16040.....	2 29.5	55 29	8.7:	B9	-0.8	(.07)	(9.0)	.....	
†16310.....	2 32.0	58 38	8.4:	B0.5	-6.0	(.45)	(11.2)	.....	
16576.....	2 34.4	55 4	7.87	A3	+1.7	(.02)	(6.0)	.....	
16964.....	2 38.1	56 8	{8.3:	A1	+0.5	(.04)	(7.5)		*
16965.....			{8.6:	A0n	+0.6	(0.04)	(7.7)	.....	

NOTES TO TABLE 4

HD No.

12856. MWC 25. $H\beta$ appears as a strong emission line. All other lines in the spectrum, with the exception of H and K, appear extremely diffuse.
12994. The Balmer series is strongly winged and somewhat broadened.
13051. MWC 27. $H\beta$ and $H\gamma$ show no trace of emission on my spectra but are somewhat weaker than in ordinary stars. The lines are not noticeably broadened.
13268. All lines somewhat broad.
13412. The spectrum shows strong lines corresponding to a type of around F0, while the K line would give a type of around A5. The star is probably a metallic-line star.
13621. ADS 1714.
13633. ADS 1717.
13661. MWC 29. $H\beta$ is fairly strong in emission, and all lines are somewhat broad.
13669. The helium lines are quite broad.
13717. The radial velocity varies from -8 to -59 km/sec.
13890. Mt. W. 249. $H\beta$ shows a very weak emission, and all lines are weak and diffuse. This star is classed as a fairly high-luminosity object because of the strength of λ 3995.
13910. The hydrogen lines are strong and appear rotationally broadened.
13970. ADS 1748. All lines are broad, and the Balmer series seems rather weak.
14434. This star, which is classed B2 in the *Henry Draper Catalogue*, appears to be classified for the first time as an O star. The lines λ 4541 and λ 4471 are of approximately equal intensity, while λ 4686 is considerably stronger than λ 4640. All lines are quite weak and diffuse except the strong interstellar lines.
14795. The hydrogen lines seem very strong for the class, and this star may be below the main sequence in luminosity.
14825. ADS 1832.
14827. ADS 1829.
14947. This O star resembles ζ Puppis in the relative intensity of λ 4686 and λ 4640 in emission. There is a possibility that $H\beta$ has a very weak P Cygni emission component. See Plaskett, *Dom. Ap. Obs.*, 2, 287, 1924.
15332. ADS 1893.
15642. All lines appear weak and ill-defined.
15690. ADS 1937.
16576. ADS 2040.
236970. ADS 1934. This is a double of 0.8" distance, and the spectra obtained are composite, of types around A2 and B2. The star is mentioned in the Mount Wilson discovery list of Be stars (*Ap. J.*, 96, 15, 1942) as one in which bright $H\alpha$ is present according to objective prism observations. When it was first taken, in Texas, only the region to the red of $H\gamma$ was well exposed, owing to the faintness and great redness of the object. This part of the spectrum matches well with α Cygni, except for the weakness of $H\beta$; and it was not until the whole spectral range was observed at Yerkes that the composite character of the spectrum was noted. Since the helium lines are fairly sharp, the observations seem capable of explanation in terms of both components of the double; but, since the difference in magnitude is given as 0.9 mag. in Aitken's catalogue, the author asked Dr. Van Biesbroeck to re-estimate the difference, which he kindly did. He finds $\Delta M = 0.5$ mag., and also noted that the star appeared about as red as a G star. It is probable, then, that we are dealing with two stars—at least one possessing emission at $H\alpha$ and weak $H\beta$. The helium line λ 4009, however, appears somewhat peculiar, as in some shells; and it is possible that the brighter component of the double is a shell star. The Si II lines do not

NOTES TO TABLE 4—*Continued*

appear noticeably weak; but, if the fainter component were of type B also, it could strengthen these lines, which are weak in typical shells.

15963. This star appears in Miss Payne's *c* star list as *cA0* and as such has been included in other lists. It shows a Cygni-like metallic lines and extremely sharp Balmer lines. However, there is evidence of an underlying broad hydrogen absorption under these sharp lines, and the helium lines $\lambda 4026$ and $\lambda 4009$ appear and are very broad. There is no doubt from the appearance of the spectrum that the "*cA0*" spectrum is produced in a shell surrounding an early-type B star. In support of the shell interpretation is the fact that the *Si II* and *Mg II* lines are conspicuously weaker in this star than in typical supergiants. See a note on this star in *Ap. J.*, 97, 452, 1943.
16012. The lines appear rather broadened.
- 16964-5. ADS 2094. The fainter component of this double has quite broad lines.

VII. THE INTERSTELLAR ABSORPTION IN THE REGION OF THE DOUBLE CLUSTER

The region of the double cluster is one fairly poor in stars, in consideration of the galactic latitude. On the reproduction of the cluster in the *Barnard Atlas*,²⁴ one sees no

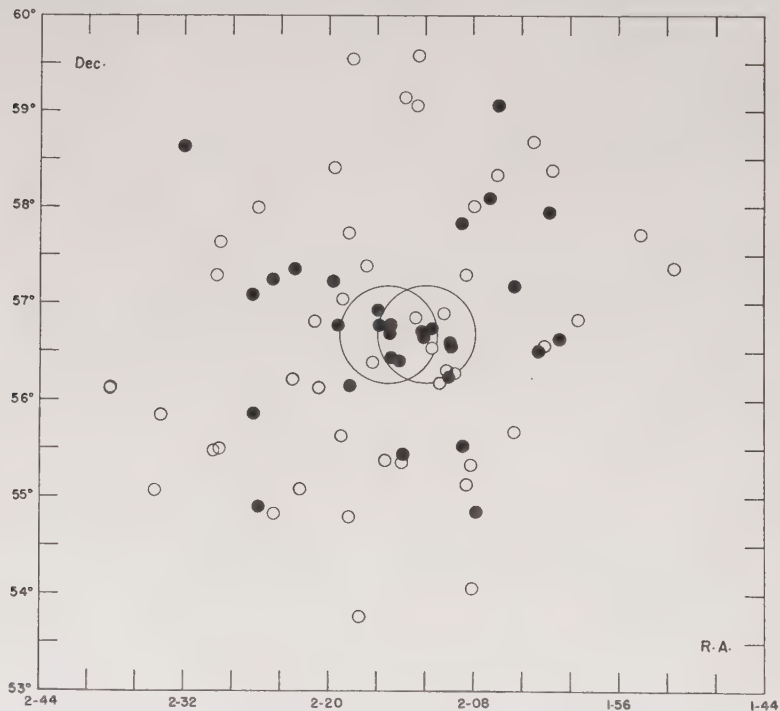


FIG. 2.—Stars with spectra as early as *A2* in the *Henry Draper Catalogue* or the *Henry Draper Extension* and with photographic magnitudes between 5.0 and 8.5 in a region symmetrical about the double cluster. Those stars which are considered to be members of the η and χ Persei cluster are represented by filled circles, while the large circles indicate the size of the two clusters as found by Trumpler for stars of the seventeenth magnitude.

particularly striking evidence of interstellar absorption; only one of Barnard's dark markings is found on that plate. One would judge by this reproduction that the η and χ Persei cluster is about at the edge of the Milky Way, for the star density falls off fairly rapidly to the upper left-hand part of the plate. That, however, is the direction *toward* the galactic circle.

²⁴ "A Photographic Atlas of Selected Regions of the Milky Way," 1927.

TABLE 5

Designation	Oosterhoff No.	m_v	Sp.	M_v	C.E.	$m_0 - M$	Re- marks
†BD 56°473.....	49	8.91	B1n	-4.3	(0.17)	(12.0)	*
†HD 13900.....	146	9.0:	B1n	4.3	(.15)	(12.2)	*
†HD 13969.....	339	8.70	B1	4.3	.13	12.1	
†BD 56°502.....	717	8.97	B1	3.8	(.22)	(11.2)	
†BD 56°511.....	847	8.91	B3	4.8	(.23)	(12.1)	
†BD 56°526.....	1133	9.23	B1n	4.5	(.24)	(12.0)	*
†BD 56°527.....	1132	8.55	B2n	4.2	(.24)	(11.1)	*
†HD 14250.....	1586	8.65	B2n	3.6	(.24)	(10.6)	*
†HD 14321.....	1781	8.96	B2	3.6	(.22)	(11.0)	
†HD 14422.....	2138	8.59	B1ne	3.8	(.28)	(10.4)	*
†BD 56°574.....	2296	8.38	B2n	4.8	(.24)	(11.5)	*
†BD 56°575.....	2299	8.88	B0.5	3.9	(.24)	(11.1)	
†BD 56°576.....	2311	8.99	B2	3.6	(.24)	(10.9)	
†HD 14476.....	2361	8.59	B0.5	3.9	.22	11.0	
†BD 56°578.....	2371	9.05	B3n	4.8	(.25)	(12.1)	*
†HD 14520.....	2541	9.09	B1	-3.8	(0.25)	(11.1)	*

NOTES TO TABLE 5

Designation

BD 56°473. Mt. W. 248. All lines quite diffuse.

HD 13900. Lines somewhat diffuse.

BD 56°526. All lines quite diffuse.

BD 56°527. Lines somewhat diffuse. Radial velocity -39 km/sec.

HD 14250. Lines somewhat diffuse.

HD 14422. MWC 37. $H\beta$ is strong in emission, while the other hydrogen lines in absorption have a peculiar appearance. All the lines in the spectrum are weak, though not especially diffuse.

BD 56°574. Lines quite diffuse.

BD 56°578. Lines somewhat diffuse.

HD 14520. ADS 1810.

TABLE 6

HD	R.A.	Dec.	m_v	Sp.	M_v	C.E.	$m_0 - M$	Re- marks
13590.....	2 ^h 7 ^m 6	63°34'	8.0:	B2	-1.5	0.22	8.0	*
14708.....	2 17.3	53 46	9.2:	B9:	+0.2	(.06)	(8.6)	
15240.....	2 22.2	56 38	8.5:	A1	+1.0	(.03)	(7.3)	
?16778.....	2 36.3	59 24	7.69	A2	-5.6	.49	9.9	*
?17145.....	2 40.0	57 15	8.0:	B8	-6.5	.45	11.4	
?17378.....	2 42.2	56 40	6.24	A4	-6.6	(.45)	(9.7)	*
18458.....	2 53.0	59 16	8.8:	B8	0.0	(0.06)	(8.4)	

NOTES TO TABLE 6

HD No.

13590. The lines appear somewhat broadened, although the star is listed in the c-star catalogue of Miss Payne. This star, as well as HD 16778 and HD 17145, was included in the program because Shapley's list of probable cluster members contains it.

16778. The radial velocity is -36 km/sec.

17378. This star has a Draper type of F5p, and a remark indicates that the spectrum is thought to be composite, consisting of an F5 and A2 component. It is called cA8 in Wilson's c-star list. The spectrum resembles the supergiant φ Cassiopeiae, which is F5p in the *Henry Draper Catalogue* but A5 according to the system of the *Atlas*, except that its K line appears to be definitely weaker than φ Cassiopeiae. Also, with respect to the rest of the metallic lines this star appears to be intermediate between the supergiants α Cygni and φ Cassiopeiae, and is thus classified as an A4 supergiant. The Balmer lines are at least as sharp as those of φ Cassiopeiae, indicating great luminosity.

Reference to the *Ross-Calvert Atlas*²⁵ shows very clearly that the small field covered by the Barnard plate is deceiving, for the cluster certainly is well in the middle of the Milky Way. Plate 6 of "The Northern Milky Way," by S. I. Bailey,²⁶ shows clearly the true relation of the cluster to the Milky Way; on this plate it is evident that the decrease in star density on the Barnard plate is due to an absorbing lane running practically parallel to the galactic circle and only $1\frac{1}{2}^\circ$ or so from the double cluster.

The effect of this absorbing lane on the stellar distribution in the region is strikingly brought out by Plate I, which has been taken from a 3-hour exposure taken by the author with the 10-inch Bruce telescope. For the reproduction of this plate I am indebted to Dr. W. W. Morgan. The absorption is seen to extend quite uniformly across the field, from slightly to the south of the double cluster; and even at a distance of only a few degrees from the cluster the absorption is very heavy, for there are numerous places where no stars show at all.

Hubble's nebular surveys²¹ show that the edge of the zone of avoidance of the extragalactic nebulae runs very close to the double cluster; nebulae have been found at galactic co-ordinates (100° , -5°) and (110° , -5°) on the southern side of the Milky Way. However, while the area to the south of the Milky Way is quite transparent, the zone of avoidance extends far above the galactic circle on the northern side. Stebbins, Huffer, and Whitford¹⁸ showed that the region of the double cluster is one of obscuration and also that there is a strong gradient of absorption extending from η and χ Persei to the galactic circle. In support of this, χ Persei is found to be considerably redder than η Persei.

This conclusion has been emphasized by Miss Pishmish,²⁷ who showed that Oosterhoff's effective wave lengths and magnitudes give evidence of a differential absorption suffered by the two clusters. Oosterhoff⁵ found that a region near η Persei (in the direction of the lower right-hand corner of Plate I) contains a much larger number of "white" stars, as shown by effective wave length, than any other part of the area he studied.

The present material, by enabling us to pick out those stars near the region which are at approximately the same distance, permits a new evaluation of the effect of selective absorption in this region. One may easily establish, by taking the color excesses from Tables 3, 4, and 5, that a strong gradient of selective absorption across the field is indeed present. From the present material there does not appear to be such a large difference between the two clusters as Miss Pishmish found, but perhaps she obtained a large effect due to selecting the opposite sides of the two clusters and thus emphasizing the greater transparency of η away from the galactic circle.

One should remember that the slightly different normal colors of supergiants which the author has used have an effect of increasing the color excesses throughout the region. The rather great value of the interstellar absorption and the rapid, although probably fairly uniform, change across the field demand accurate measurement of the colors of the stars if we desire to use them to calibrate our supergiant absolute-magnitude scale.

VIII. THE DISTANCE OF THE CLUSTER

On the basis of the present material the distance of the cluster surrounding η and χ Persei and the double cluster itself may be found in several ways: (a) by the absolute magnitudes of the stars brighter than magnitude 7.5 (Region I); (b) by the absolute magnitudes of the stars between magnitude 7.5 and 8.5 (Region II); (c) by the absolute magnitudes of those stars which almost certainly belong to the cluster (Region III); (d) by the main sequences of the Russell-Hertzsprung diagrams of the two clusters observed by Trumpler,^{12,13} and (e) by the radial velocities of the brighter stars, assuming the effect to be due to galactic rotation.

²⁵ "Atlas of the Milky Way," 1936.

²⁶ *Harvard Ann.*, **80**, 83, 1917.

²⁷ *Harvard Bull.*, No. 915, 27, 1941.



THE MILKY WAY IN THE REGION OF THE h AND χ PERSEI CLUSTER

The galactic circle is indicated, and the scale may be judged from the galactic latitude of the cluster, -3° . The decrease in star density toward the upper left-hand corner of the plate is striking. The symmetrical bright areas about the brighter stars are not considered as evidence of nebulosity.

Deciding definitely on the cluster membership of a star is difficult, since there are no observable criteria which guarantee membership. Consequently, the question of cluster membership has been decided principally on the grounds of spectroscopic absolute magnitude and radial velocity. For all stars plotted in Figure 2, i.e., material complete for early-type stars brighter than photographic magnitude 8.5 in the region covered, a frequency-curve of distance modulus was plotted, using $\frac{1}{2}$ -mag. intervals in distance modulus. This curve is fairly uniform except near distance modulus 11.0, where there is a considerable excess; and this was assumed as a provisional value of the distance modulus of the cluster of supergiant stars surrounding the double cluster. With the aid of this provisional value and with consideration of radial velocities whenever available and the intensity of the interstellar K line, the stars marked in the tables with daggers were determined to be probable cluster members. Those with question marks may possibly be cluster members. On this basis we may have left out several true members, but it was felt desirable to compute the distance of the cluster from only those stars which are quite certainly members. We then find the following results:

- a) From 14 stars in Table 3 we find a mean $m_0 - M$ of 10.9 mag.
- b) From 15 stars in Table 4 we find a mean $m_0 - M$ of 11.1 mag.
- c) From all the stars in Table 5 we find a mean $m_0 - M$ of 11.4 mag. There can be little doubt that all these stars belong to the cluster, because of their close similarity in absolute magnitude, spectral class, and interstellar line appearance. The absolute magnitudes are, however, somewhat difficult to estimate, owing to the wide spectral lines of many of these stars.
- d) The Russell-Hertzsprung diagram for h Persei was plotted from the data given by Zug,¹³ using Trumpler's classes and Zug's magnitudes. Although the dispersion is considerable, the average of the B9 stars is about apparent photographic magnitude 12.1. When Oosterhoff's magnitudes are used for the same cluster, the dispersion is somewhat reduced, and the average of the B9 stars is at about 12.0. Using Trumpler's¹² magnitudes and spectra for χ Persei, we find the average of the B9 stars at about 12.5 photographic. Although the exact value of the difference is in considerable doubt, as the scatter is large and the spectral composition may not be the same for both clusters, the effect is in the direction remarked by Miss Pishmish. Since we wish the corresponding visual magnitudes, we must correct both for normal color index, which we assume to be -0.2 mag., and for the coloring effect of the interstellar absorption suffered. Following Stebbins, Huffer, and Whitford, we assume that the latter is given by two times the photoelectric color excess; and, if we adopt a color excess of 0.22 for h Persei and 0.25 for χ Persei, we obtain for the apparent visual magnitude of the B9 stars 11.8 and 12.2 for h and χ Persei, respectively.

We must now adopt a visual absolute magnitude for the B9 stars in the double cluster. This value must be uncertain to some extent because we cannot be sure that the "main sequence" stars in the cluster occur at the same absolute magnitudes as for stars in general, without spectra of stars which have not been studied in this work. But in general it is clear that the average of the B9 stars should not be given the absolute magnitude corresponding to class V on the system of the *Atlas*, for what is commonly termed "main sequence" is generally a mixture of stars of luminosity class III, IV, and V. The author has adopted -0.5 as the visual absolute magnitude to use in this connection, suggested by Dr. W. W. Morgan. Using this value and applying the total visual absorption correction, we arrive at true distance moduli of 10.7 for h Persei and 11.0 for χ Persei.

- e) Using radial velocities with probable errors no greater than ± 2 km/sec for the stars which are considered certain members of the cluster, we find the average radial velocity of -41.9 km/sec. For the average of these stars we adopt a correction of $+3$ km/sec for the local solar motion. Taking Oort's constant A as 18 km/sec/kiloparsec,²⁸ we deter-

²⁸ Chandrasekhar, *Principles of Stellar Dynamics* ("Astrophysical Monographs"), 1942.

mine the distance of these stars as 2180 parsecs, which corresponds to a $m_0 - M$ of 11.7.

Since it is difficult to estimate the relative reliability of the various distance determinations made on the basis of spectroscopic absolute magnitudes, we have taken the mean of the first four values as the "spectroscopic distance." This distance, computed from $m_0 - M = 11.1$, comes out as 1660 parsecs. Hence there is a considerable discrepancy in distance, though only a fairly small one in distance modulus, between the spectroscopic and the radial velocity determinations. It is perhaps of importance that the distance obtained from the stars in Table 5 agrees the best with that obtained from the radial velocities. In fact, in so far as the stars above the main sequence in η and χ Persei are concerned, we may bring the two distance determinations into agreement by increasing the absolute magnitudes of our supergiants and giants by about 0.6 mag. (undoubtedly a permissible correction), by decreasing the color excesses somewhat, or by lowering somewhat the ratio between total and selective absorption. On the other hand, a peculiar motion of about -9 km/sec on the part of the entire η and χ Persei system would again bring the two distance determinations into agreement. This latter situation is, however, unlikely in view of the high masses of these stars.

Wilson¹ finds a discrepancy of the same order as the above between the distance of the cluster as judged from absolute magnitudes and radial velocities. Further, Evans⁷ finds that the distance of η and χ Persei found from the strength of the interstellar lines is considerably smaller than that found from the radial velocities, which possibly indicates a peculiar motion of the stars. However, he says that the stellar and interstellar velocities agree in giving the same distance, which shows that the peculiar motion of the stars must be small, if we assume that the interstellar medium has little peculiar velocity.

It appears to the author as though the most probable cause of the discrepancy is an error in the absolute magnitudes, which may be caused either by a systematic error in the luminosity classes of this work or by a systematic error, for the most luminous stars, in the preliminary reduction curves used. At any rate, such an error would be fairly small, and we may conclude that the current estimates of the absolute magnitudes of early-type supergiants are probably not too high.

Taking the mean of the distances determined from the absolute magnitudes and the radial velocities, we obtain $r = 1920$ parsecs. With this distance the projected distance of the centers is 14 parsecs; the radius of each cluster 7 parsecs, according to Oosterhoff;⁵ the radius of each cluster 17 parsecs, according to Trumpler's work on η Persei;¹¹ and the total diameter of the "extended cluster" of supergiants 167 parsecs, assuming an apparent diameter of 5° .

IX. OTHER CONSIDERATIONS

Interstellar calcium intensity.—As would be expected for distant stars, the majority of the early-type stars in this region show a strong interstellar K line. In fact, among all the stars observed as B5 or earlier, the K line is weak only in the following stars: HD 8965, 9812, 13590, 13661, 13669, 14722, 18352, and absent only in HD 11606 and 14871. All stars attributed to the cluster have interstellar lines of about the same intensity. A few early-type stars which were classified as of low luminosity have quite strong interstellar lines. Those showing the greatest discrepancy are HD 13831 and 13970, the lines of both of which are somewhat broad.

The broad-line stars in η and χ Persei.—Trumpler¹² showed that in the cluster χ Persei the Be stars are limited to a rather small range in absolute magnitude. These stars are, in general, somewhat fainter than those considered in the present work. It is of interest, however, to note that of the stars in Table 5, 8 stars, or one-half, have lines to some degree diffuse. It seems quite probable that we observe here an interval of absolute magnitude in which the stars are subject to rapid rotation, without, however, the speed of rotation being such that emission occurs. With decreasing absolute magnitude the rotational

speed apparently increases. The double cluster thus contains two types of emission stars: supergiants bright at $H\alpha$ and rapidly rotating giants and dwarfs usually bright at both $H\alpha$ and $H\beta$ and often showing practically continuous spectra at $H\gamma$.²⁹

Later-type members of the double cluster.—It is interesting to consider whether supergiants of later type are also present in the "extended cluster" of supergiants surrounding η and χ Persei. Evidence confirming this supposition is shown in Keenan's work³⁰ on the luminosities of the M-type variables of small range. Figure 3 is plotted from Keenan's table and shows only the more luminous supergiants; the grouping about the position of the double cluster is very conspicuous. It is of importance in the present connection that 2 of the 5 supergiants in this grouping are at as much as 2° from η and χ Persei. The hypothesis of cluster membership for these stars is confirmed to some extent by the radial

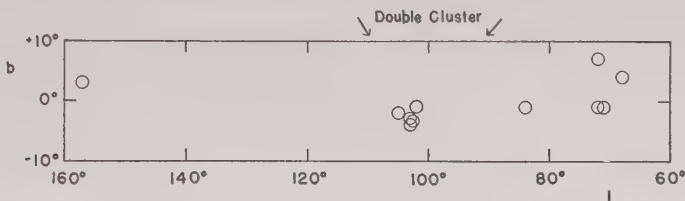


FIG. 3.—Distribution of the most luminous supergiants among the M-type variables of small range according to Keenan, *Ap. J.*, **95**, 461, 1942. Since "the material is reasonably complete down to the ninth apparent magnitude" over this area, the clustering of five of these objects close to the double cluster in Perseus is undoubtedly significant.

velocities of Joy.³¹ There is a cF8 star attributed in Wilson's catalogue to the double cluster, but its radial velocity of -26.2 km/sec excludes it.

From the work of Joy³² on the radial velocities of Cepheid variables one sees that several of these stars may be, from radial velocity and absolute magnitude evidence, members of the grouping of supergiants around the double cluster. The possible members of this group include VX Persei, UX Persei, UY Persei, and SZ Cassiopeia.

It is well known that there is an extraordinarily rich clustering of faint Be stars in the region of the double cluster. The plot of the galactic distribution of faint Be stars in the paper of Merrill and Burwell²² shows clearly that this clustering has an extension comparable with that found from the early-type supergiants. Of course, some of the stars are the same, since many supergiants have bright $H\alpha$; but the clustering is marked over a fairly large region for stars much fainter than those considered here. Although the absolute magnitudes of the emission stars are more uncertain than those of normal stars, and we therefore cannot say definitely that these stars are at the distance of the cluster, it would be unusual if this rich apparent clustering were not the reflection of a physically connected group of stars.

The Russell-Hertzsprung diagram for the brighter stars of η and χ Persei.—Figure 4 is the absolute magnitude-spectral class diagram obtained by using those stars of Tables 3, 4, and 5 and those given in the lists of Trumpler and Zug which are considered to be members of the η and χ Persei cluster. Ordinates are the visual apparent magnitudes which the stars would have were there no interstellar absorption; these were obtained by use of the photoelectric color excesses, and for the fainter stars by considering both color

²⁹ Beals (J. R.A.S., Canada, **34**, 190, 1940) has found that 5 of the supergiants studied in the present work, HD 12953, 13841, 14134, 14143, and 14818 are P Cygni stars. Since 2 of these stars were not discovered to be emission stars by the Mount Wilson observers, it appears that the majority of highly luminous early-type stars show slight P Cygni characteristics at some times.

³⁰ *Ap. J.*, **95**, 461, 1942.

³¹ *Ap. J.*, **96**, 344, 1942.

³² *Ap. J.*, **89**, 356, 1939.

excess and normal color index. The ordinate scale thus differs only in zero point from the visual absolute magnitudes; this would not be so if we merely plotted apparent magnitudes, because of the differential interstellar absorption suffered by the stars. For the stars in Table 3 Harvard photometric magnitudes have been used. The stars represented by the larger filled circles have been observed in this investigation, and the author's classes have been used; those stars represented by the smaller filled circles were studied by Trumpler and Zug. Actually, all of the stars listed by Zug are included; but for Trum-

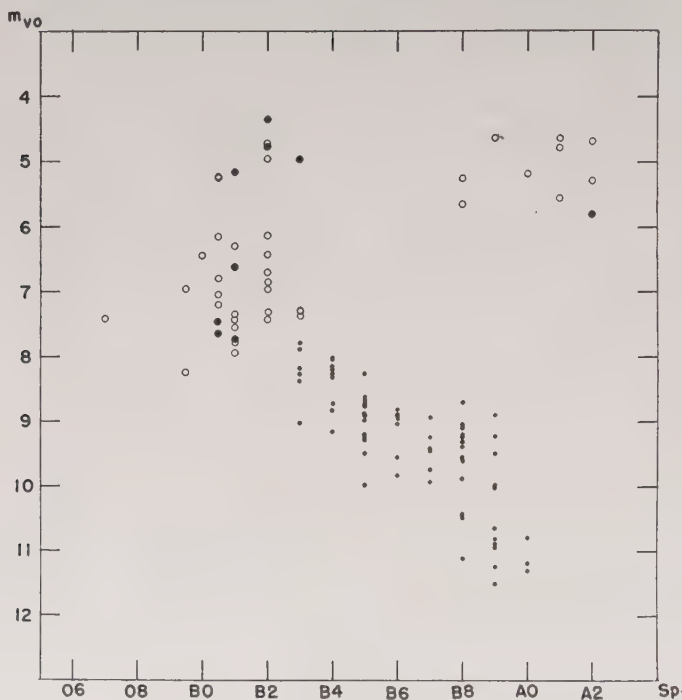


FIG. 4.—Russell-Hertzsprung diagram for stars considered to be members of the double cluster. The ordinates are the visual magnitudes which the stars would have were there no interstellar absorption. The larger circles represent stars studied in the present work, the smaller, filled circles those stars classified by Trumpler. Large filled circles denote emission stars, the five most luminous stars having sharp lines and bright $H\alpha$ and the four less luminous stars having broader lines and usually $H\beta$ also in emission. Several of the stars studied by Trumpler also belong to the latter class. Two supergiants, HD 15316 Sp. A2, and HD 15497, Sp. B5, although probably cluster members, are omitted because of their abnormally high color excess and the consequent uncertainty in the correction for absorption. The two open circles at (A1, 4.6) and (B0.5, 6.2) should also be filled, as Beals has found these stars to be P Cygni stars.

pler's stars, only those which he lists (the brighter stars) have been used. Hence the lower part of the diagram refers exclusively to stars in h Persei. However, the diagrams are similar for h and χ Persei and differ only in zero point, which is probably caused by the different amount of interstellar absorption in the two. The larger filled circles refer to stars showing emission, either supergiants with emission at $H\alpha$ or lower-luminosity stars with emission at several hydrogen lines.

There is some uncertainty in the position in the diagram of the fainter stars, owing to uncertainty in color excess. However, if we assume a distance modulus of 11.1 (as found from the spectroscopic evidence, with little uncertainty), we can transform the diagram

into one involving absolute magnitudes. Doing this, we see that the stars near class A0 are more or less around the main sequence but that the stars around B1 average considerably above it, being largely members of luminosity class III. Of course, there may be fainter stars in the cluster of early spectral class which have been heretofore unrecognized. Barring this, there is little doubt that the "main sequence" turns upward very sharply in this cluster in the earliest spectral classes. The same effect has been noted for galactic clusters before by Trumpler.³³

If the distance is assumed to be given correctly by the radial velocities, then the main sequence of the cluster stars must be somewhat above that of stars in general.

In connection with the Russell-Hertzsprung diagram, it must be remembered that, while our data on the upper part of the diagram are essentially complete, aside from the possibility that several more of the stars listed in the Tables 3, 4, 5, and 6 may be cluster members, the faint stars have been observed over only a very small area about the centers of the two clusters. It seems quite likely, however, that there are few normal giants of spectral class around A0 in the cluster.

Dynamical considerations.—It is rather difficult to compute the quantities of dynamical interest for the η and χ Persei cluster, since we do not know the number of stars or the total mass. For our present purpose we assume (for one cluster) the number of cluster stars as 1000 and the total mass as 2500 solar masses. Also, for dynamical purposes it probably is more correct to use the smaller value of the radius suggested by Oosterhoff,⁵ as most of the stars are within this limit.

From the formulae given by Chandrasekhar²⁸ we find the following:

- a) The dispersion of the residual velocities equals 0.88 km/sec.
- b) The time of relaxation equals 1.3×10^8 years. It follows from the work of Chandrasekhar, who has recently shown that clusters can hold their members for times of the order of one hundred times the time of relaxation, that we cannot picture the supergiants in the region of the double cluster as having "escaped" from it in a time of the order of the age of the universe.
- c) The average density of the clusters is about 1.7 solar masses per cubic parsec, which shows that the small clusters, with radii of 7 parsecs, will be stable, even considering the tidal action of galactic rotation, if the distribution of potential within the clusters can be approximated to that of a homogeneous ellipsoid.

However, the above considerations do not indicate whether the stars situated at great distances from the center of the double cluster are primarily subject to its influence, or, if they are, whether they will continue to be so. This matter is closely linked with the problem of the stability of star clouds and leads to the question of maintenance of fluctuations of density in the Galaxy.

The writer wishes to thank Dr. O. Struve for the privilege of being at the Yerkes Observatory, Dr. W. W. Morgan for suggesting the problem and for valuable advice, and also Dr. S. Chandrasekhar and Dr. H. F. Weaver for helpful discussions of several questions.

³³ *Lick Obs. Bull.*, No. 420, 1930.

